(12) UK Patent Application (19) GB (11) 2 144 868 A

(43) Application published 13 Mar 1985

(21) Application No 8321391

(22) Date of filing 9 Aug 1983

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(51) INT CL[4]
G02F 1/03

(52) Domestic classification
G2F 21C 22 23E 25S 28W CW
U1S 2091 2208 G2F

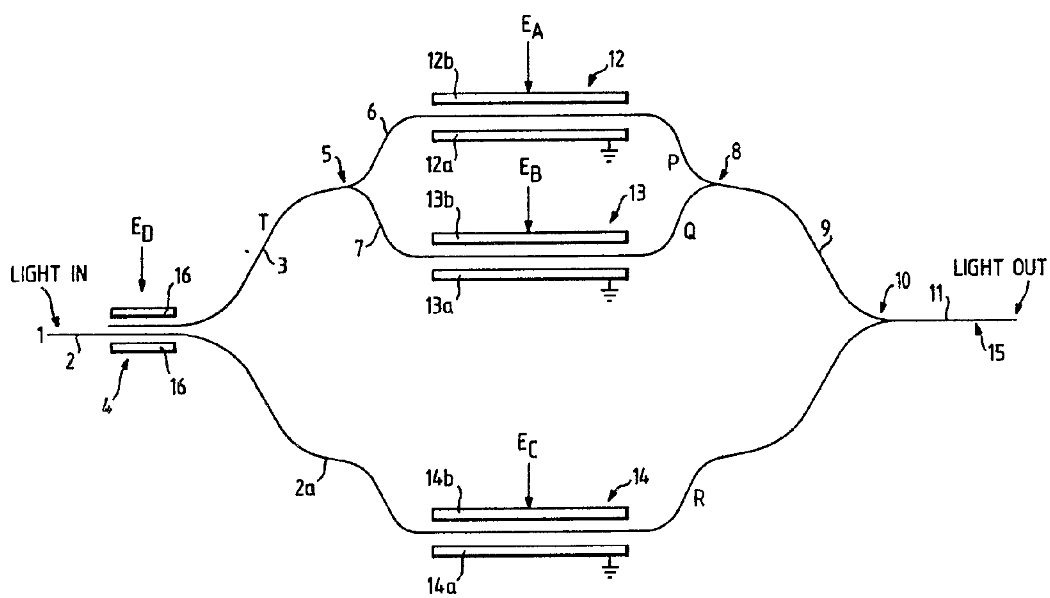
(56) Documents cited
None

(58) Field of search
G2F

(54) Integrated optic arrangement

(57) An integrated optic channel waveguide device (20) includes three waveguide arms (3,6,9; 3,7,9; 2a) of substantially identical optical length. Sinusoidal electrical signals (E_A, E_B) of frequency f_m and substantially in quadrature are applied to two electrode arrangements (12, 13), whereas a d.c. control signal (E_C) is applied to the third electrode arrangement (14). A required phase ($\emptyset_R$) of the electrical output signal of a detector subsequent to filtering is achieved via an appropriate phase shift caused by suitable choice of the d.c. control signal (E_C). The output of the detector includes terms with frequency F_m and odd orders thereof, i.e. $3f_m$, $5f_m$ etc. Thus in dependence on the bandpass of the post-detection filter, electrical signals of higher frequency than the input electrical signal frequency (f_m) can be obtained. The device is used as part of a system for the generation and transmission of very high frequency electrical signals with controllable phase on an optical carrier.

Fig.1.



The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

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Fig.1.

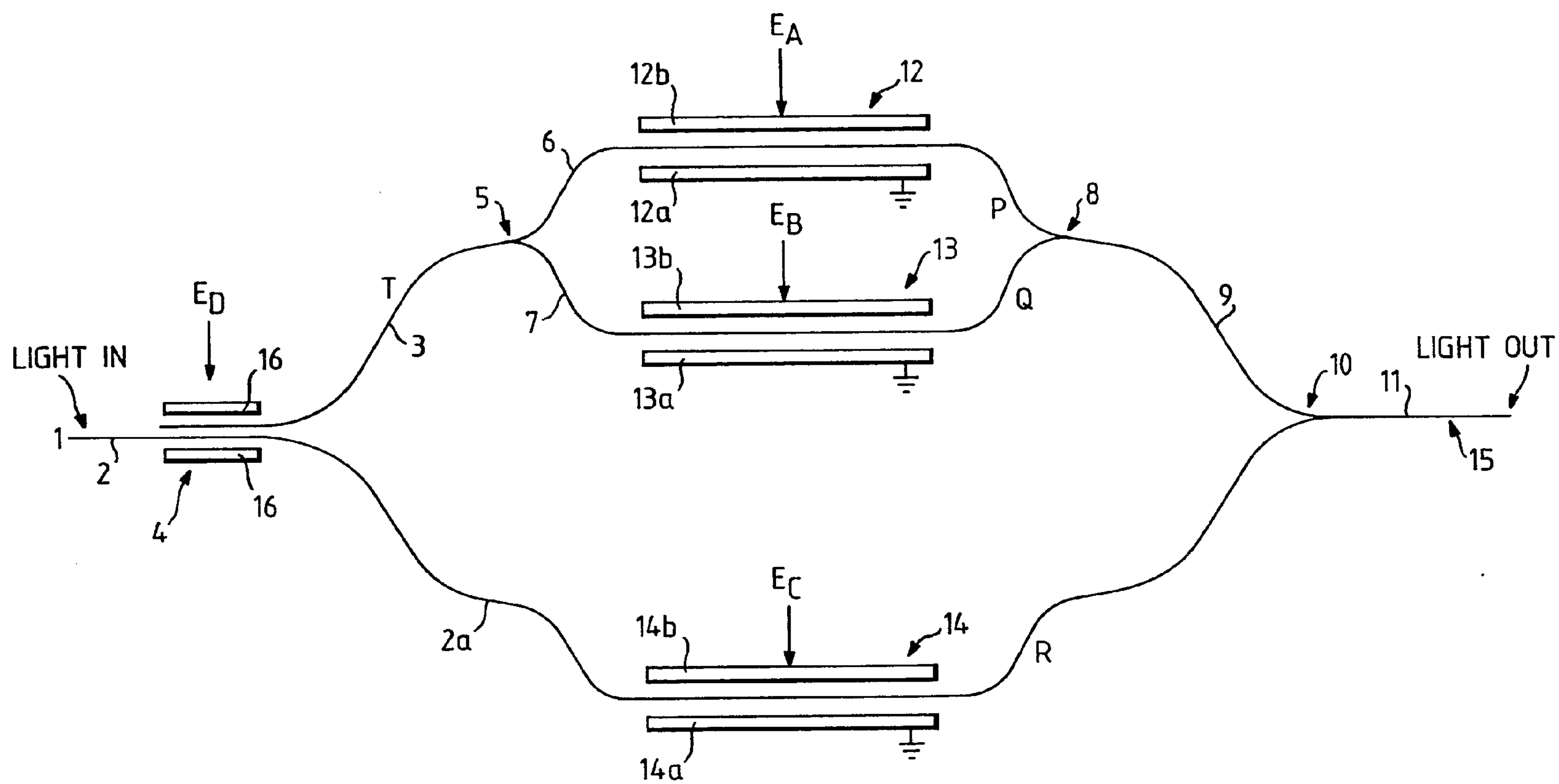

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Fig. 2.

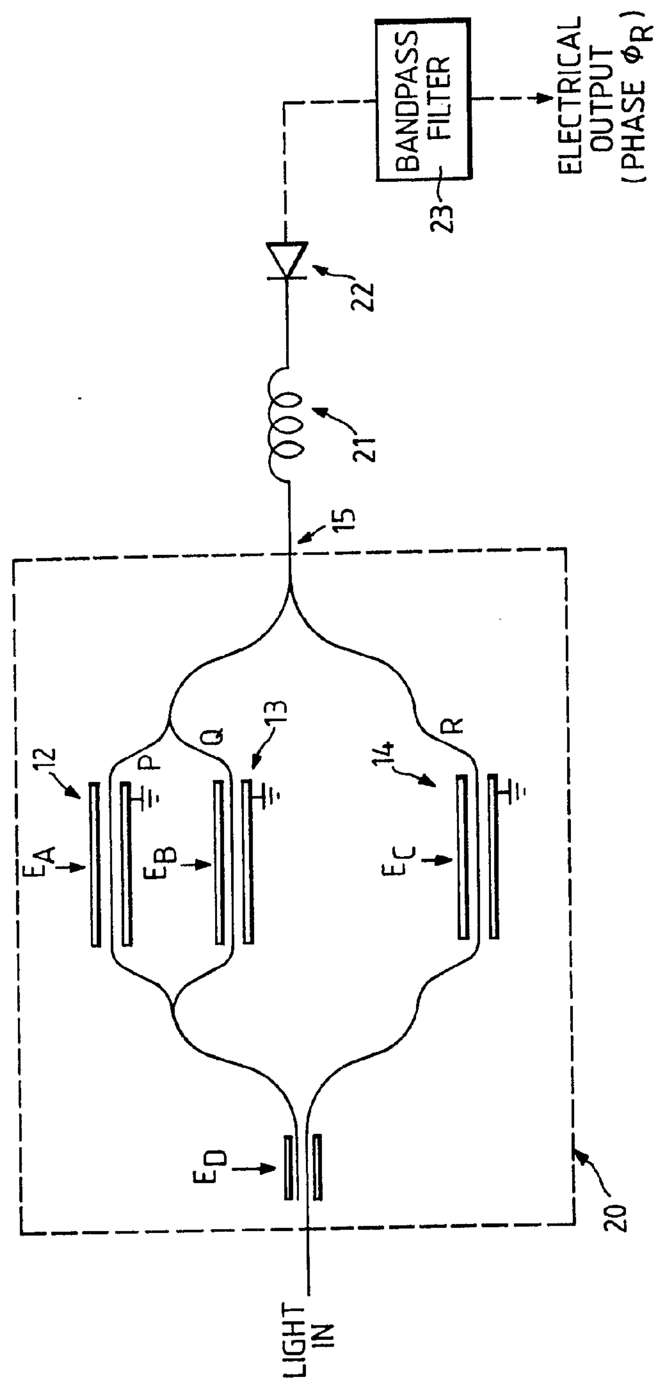
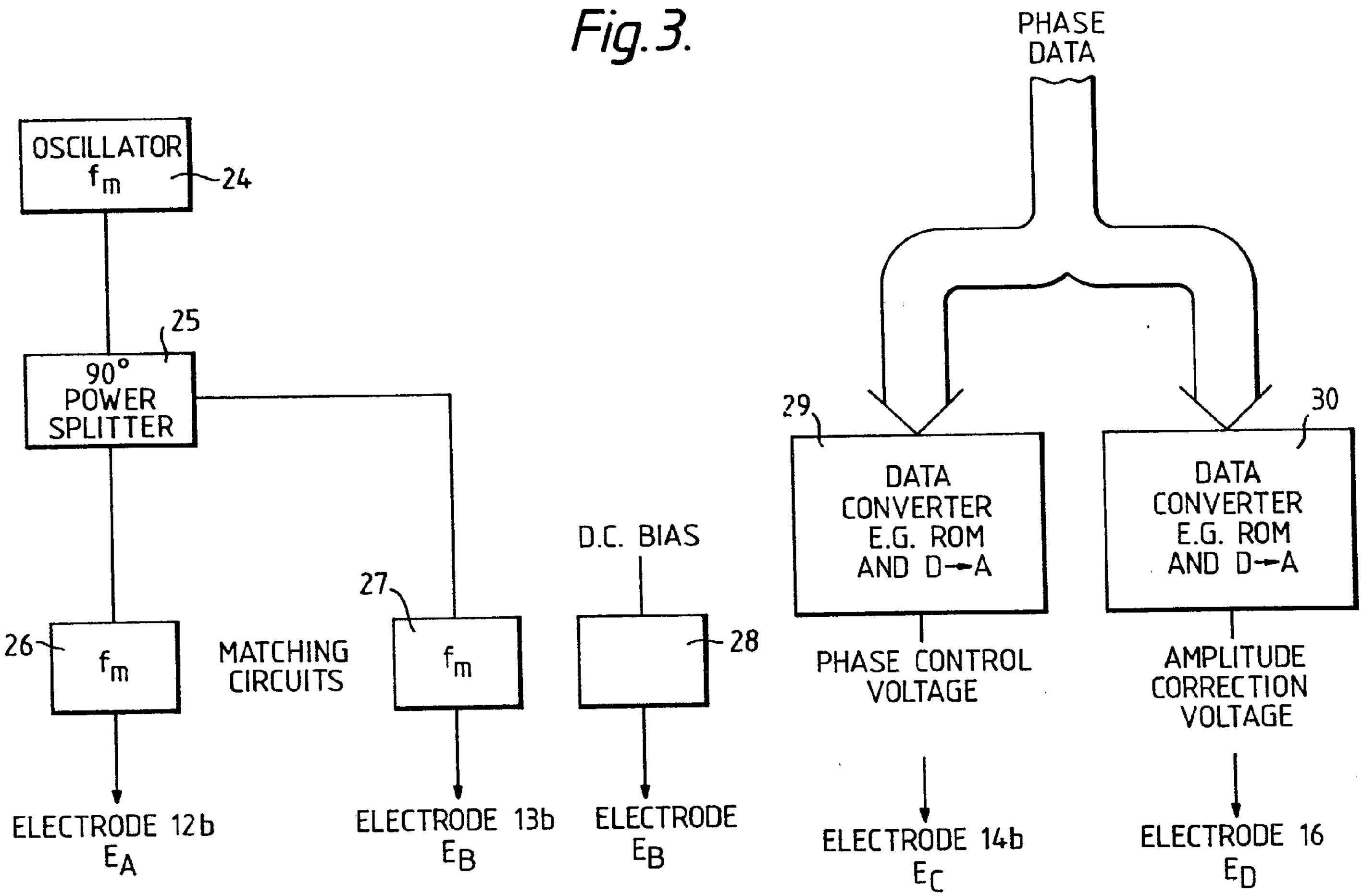


Fig. 3.



PHASE DATA
OSCILLATOR f_m
24
25
90° POWER SPLITTER
29
30
DATA CONVERTER E.G. ROM AND D→A
DATA CONVERTER E.G. ROM AND D→A
D.C. BIAS
27
26
f_m
MATCHING CIRCUITS
f_m
28
PHASE CONTROL VOLTAGE
AMPLITUDE CORRECTION VOLTAGE
ELECTRODE 12b E_A
ELECTRODE 13b E_B
ELECTRODE E_B
ELECTRODE 14b E_C
ELECTRODE 16 E_D

SPECIFICATION

Integrated optic arrangement

This invention relates to an integrated optic arrangement usable for the phase control and optical generation and transmission of electrical signals.

In our co-pending Application No. 8111096 (Serial No ......) (G.D.H. King–M.C. Bone 7–1) there is disclosed an integrated optic device including a single mode optical waveguide which diverges into two waveguide branches of identical optical length that subsequently converge into another single waveguide. The optical properties of the two branches are variable by electrical fields applied via adjacent electrodes. The electrodes are energised with a composite waveform comprising a symmetrical ramp superimposed on a square wave of the same period. The two component waveforms are in phase but of different amplitudes such that the output light is intensity modulated at a frequency which is some multiple of the input waveform (frequency upconversion). Adjustment of the square amplitude provides the means of phase shifting the output signal. The optical output of this device consists of at least three optical frequencies.

In our co-pending Application No. 8230253 (Serial No ......) (M.C. Bone–J. Moroz 4–3) there is disclosed an integrated optic device including a single mode optical waveguide which diverges into three waveguide branches, of substantially identical optical length, that subsequently converge into another single mode waveguide. The optical properties of the branches are variable by electrical fields applied via adjacent electrodes. The electrical fields applied to two of the branches include sinusoidal signals of frequency f_o, substantially in quadrature, whereas the electrical field applied to the third branch includes a sinusoidal signal of frequency $2f_o$. In dependence on electrical phases, an optical signal of optical frequency f_c input to the device is output therefrom with its frequency upshifted to $(f_c + f_o)$ or downshifted to $(f_c - f_o)$. The optical output is substantially single frequency. The basic three branch device comprises an optical single sideband modulator. By adding a fourth (reference) waveguide branch a device for use in an optical phase shifter can be obtained. In that application an electrical signal frequency f_o is transmitted on an optical carrier signal, with optical frequency f_c, and the detected phase of the frequency f_o is controllable. The fourth branch acts as a reference branch whose output is a reference optical signal with frequency f_c. Application of a predetermined voltage signal to the electrode arrangement associated with the fourth branch causes a phase shift ϕ to appear on the reference optical signal having an optical frequency f_c. Thus this device generates two optical signals, one at frequency $(f_c + f_o)$ or $(f_c - f_o)$ and a second at $(f_c + \phi)$. When the various optical signals are detected at the output of the device, for example with a photodiode, the effect of the phase shift on the reference signal is such as to cause the phase of the detected signal of frequency f_0 to change by an amount ϕ. This fourth-branch waveguide device thus provides a means of transmitting an electrical signal frequency f_o of controllable phase shift ϕ on an optical carrier signal, the phase shift ϕ being controllable by varying the voltage signal applied to the electrode arrangement associated with the fourth branch. Alternatively by modification of the device structure the phase shift ϕ may be caused to appear on the frequency shifted signal $(f_c \pm f_o)$ rather than the reference signal (f_c). This also allows the transmission of a signal of frequency f_0 of controllable phase shift ϕ on an optical carrier signal.

According to the present invention there is provided an integrated optic arrangement including an integrated optic device and electrical drive means therefor, which device includes a substrate of electro-optically responsive material in which are defined an input optical waveguide, first second and third optical waveguide arms of substantially identical optical length, and an output optical waveguide, wherein the input optical waveguide is optically connected to each of the first second and third waveguide arms at their input ends, which first second and third waveguide arms converge at their output ends into the output waveguide, wherein a respective conductive electrode arrangement is disposed adjacent a portion of each waveguide arm whereby in use of the arrangement electrical fields for modifying the optical properties of the waveguide arm portions can be generated, and wherein the electrical drive means is such as to provide first and second sinusoidal electrical signals of frequency f_m for application to the electrode arrangements of the first and second waveguide arms, respectively, which first and second signals are substantially in quadrature, and such as to provide a d.c. electrical control signal for application to the electrode arrangement of the third waveguide arm, whereby in use of the arrangeent electrical signals of frequency f_m, and odd multiples thereof, and of controllable phase are generated and transmitted on an optical carrier signal input to the device, the phase of the transmitted electrical signal being controlled by the d.c. control signal and thus the phase of the optical signal in the third waveguide arm portion.

Whereas phase control was obtained in our co-pending Application No. 8230253, it was achieved with an integrated optic device including four waveguide branches, the present

invention achieves phase control with a three waveguide branch device.

Embodiments of the present invention will not be described with reference to the accompanying drawings, in which:

Figure 1 shows a waveguide arrangement for an integrated optic device.

Figure 2 shows a schematic arrangement of an optical transmission system utilising the waveguide arrangement of Fig. 1, and

Figure 3 shows a block diagram of drive and control electronics for use with the waveguide arrangement of Fig. 1.

The waveguide arrangement illustrated in Fig. 1 is only an example, a number of different waveguide plans may alternatively be employed. The essential feature of the waveguide plans is that three waveguides or waveguide branches derive their light from a single waveguide and then recombine their light into a single waveguide. In Fig. 1, light from a laser (not shown) is input at 1 to a waveguide 2 and optical energy is coupled to a waveguide 3 by means of an optical coupler 4. The waveguide 3 diverges at 5 into two waveguides 6 and 7, which reconverge at 8 to form waveguide 9 which converges with waveguide 2*a*, which is a continuation of waveguide 2, at 10 into an output waveguide 11. The waveguides are preferably all single mode, that is they only transmit single mode optical energy, for best results. Associated with each waveguide 6, 7 and 2*a* is a respective conductive electrode arrangement 12, 13, 14, each comprising two electrode portions arranged adjacent to the respective waveguide. One electrode portion 12*a*, 13*a*, 14*a* of each arrangement is earthed. Electric fields can be applied to the separate waveguides by applying respective electric signals E_A, E_B, E_C to electrode portions 12*b*, 13*b*, 14*b*. The waveguides are defined by regions of increased refractive index in a substrate of an electo-optically responsive material, for example lithium niobate ($LiNbO_3$). The waveguide regions may be formed by indiffusion of suitable materials, such as titanium or nickel oxide, or by the ion implantation of suitable materials, such as helium, to provide suitable single mode waveguides. The conductive electrode arrangements 12, 13 and 14 comprise metallic layers deposited on the surface of the substrate substantially parallel to the respective waveguides. For optimum operation the three waveguide branches (arms) should be of substantially similar optical length. Light is input to the waveguide 2 at point 1 from a laser on a fibre by some suitable coupling means. and light is output at point 15 by some suitable coupling means. The waveguides 2 and 3 are closedly spaced in the optical coupler 4 which has electrodes 16. Fine adjustment of the optical energy going into the waveguide 3 can be achieved by applying a signal E_D to generate an electric field between electrodes 16.

The effect of the electrical fields produced by signals E_A, E_B, and E_C is to modify the properties of the waveguide regions between the respective electrodes of each of the arrangement 12, 13 and 14 such that the velocity of light therethrough is changed. This in turn varies the transit time of the light through the respective waveguide regions. The result of this, to a good approximation up to very high frequencies of applied voltage to the electrodes, is a phase shift of the light. Thus the three waveguide arms 6, 7 and 2*a* with their electrode arrangements 12, 13 and 14 act as three independent optical phase shifters.

In order for this basic three branch waveguide arrangement to operate for phase control, instead of requiring a fourth branch as described in Application No. 8230253, electrical signals of the modulation frequency are applied to two of the branches 6 and 7, and a d.c. control signal is applied to the third (reference) branch 2*a*.

The theoretical operation of the device of Fig. 1 will now be considered. Light of frequency f_c is input into the device. The output light will also contain frequency f_c with sidebands at frequencies $(f_c \pm f_m)$, $f_c \pm 2f_m)$, $(f_c \pm 3f_m)$, etc., where f_m is the electrical modulation frequency. By applying the electrical modulations with appropriate relative phase and amplitude the odd order sidebands may be made substantially single sideband, that is the output can be made to comprise signals at $(f_c(\pm)f_c)$, $(f_2(\pm)3f_m)$, $f_c(\pm)\ 5f_m)$, etc., where the signs in brackets constitute an alternative combination. It is this single sideband nature which allows the control of the phase of the frequency f_c in the reference arm R to control the phase of the detected electrical signal.

Assuming the light amplitude at input 1 is of the form cos $2\pi f_c t$ then the amplitude S_p, S_q and S_r of the optical signals in the waveguide arms P, Q and R are as follows, namely:–

$$S_p = P \cos [2\pi f_c t + \phi_1 + A \sin (2\pi f_m t + \phi_4)]$$
$$S_q = Q \cos [2\pi f_c t + \phi_2 + B \cos (2\pi f_m t + \phi_5)]$$
$$S_r = R \cos [2\pi f_c t + C]$$

where,

P, Q, R are the peak amplitudes of the optical signals in the respective waveguide arms;

f_c is the optical frequency of the light input;

f_m is the frequency of the electrical signal applied to specific electrodes;

t is time;

A,B,C are the amplitudes of the phase shifts induced by the various electrical signals, and $\phi_1, \phi_2, \phi_4, \phi_5$ are phase terms.

Ideally, the driving signal on the electrodes E_A and E_B are two signals of frequency f_m in quadrature, and the amplitudes of the phase shifts A and B should be equal.

The device is tolerant of deviation of the above parameters from ideal, however better

performance will be achieved as the parameters tend towards the following relationships, namely:–

P equals Q.	A equals B.
$\phi_1 = \phi_2 + \pi/2$	$\phi_4 = \phi_5$

Improved linearity between the applied control phase C and the phase ϕ_R of the detected electrical signal is achieved by making R larger than P or Q. This also reduces the variation in amplitude of the detected electrical signal with control phase C. The following is a set of values that could be used:–

P:Q:R	= 1:1:8
A;B	= 1.9; 1.9

$\phi_1 = \phi_4 = \phi_5 = o$,	$\phi_2 = -\pi/2$
f_m, f_c as chosen,	C as chosen.

The above values were chosen for fundamental operation. If it is desired to operate at the third harmonic, i.e. where the frequency of the detected electrical signal is three times the frequency of the applied electrical signal f_m, then A = B = 3.9 should be used. The exact value of R is not critical. C is determined by the d.c. control signal applied to electrode E_c. The remaining non-linearity in variation between C and ϕ_R can be removed by use of a ROM that translates an input digital signal indicating a desired value of ϕ_R into a corrected value of C such that the desired ϕ_R is exactly achieved. In addition a second ROM can alter the control voltages on the optical coupler to adjust the value of the relative power split between arms T and R such that the amplitude of the detected electrical signal is kept constant whatever the value of C.

A practical implementation of an optical transmisssion system is shown in Fig. 2 and a block diagram of the drive and control electronics therefor is shown in Fig. 3. The device of Fig. 1 may be of the form of an integrated optic chip 20 in the system of Fig. 2 Light output at 15 from the device is transmitted via free space or over an optical link 21, which may be comprised by an optical fibre, to a detector 22 comprised, for example, by a photodiode. The optical signal is detected at the photodiode detector 22 and the electrical output thereof is bandpass filtered at a filter 23. This post detection filtering is such as to remove all but the desired electrical frequency, that is only f_m is allowed to pass in fundamental operation, or $3f_m$ is third harmonic operation. Improved performance in terms of maximum frequency f_m and signal to noise ratio is achieved if an optical fibre used for the optical link 21 has low dispersion and is single mode. The output of filter 23 has phase ϕ_R.

The elctrical signals E_A and E_B applied to the electrode arrangements 12 and 13 consist of a d.c. bias plus a sinusoidal signal of frequency f_m. Alternatively, the d.c. biases may be applied to separate electrodes on the waveguide arms P and Q (6 and 7) prior to the electrode arrangements 12 and 13. The d.c. biases set the phase ϕ_1 and ϕ_2. The amplitudes of the respective sinusoidal signals of frequency f_m, E_A and E_B, set the values of A and B. These two signals are 90 degrees out of phase, thus setting ϕ_4 and ϕ_5 to the same value. A d.c. control signal comprises electric signal E_c and this sets the value of the phase shift C.

As illustrated in Fig. 3 the signals E_A and E_B may be obtained by means of an oscillator 24 having an output signal of frequency f_m. The output of oscillator 24 is applied to a 90° power splitter 25 whose outputs are applied to respective matching circuits 26 and 27 before application to electrodes 12*b* and 13*b*. The output of a source of d.c. bias is applied to electrode E_B after application to a matching circuit 28. Phase data comprising the input digital signal indicating the desired value of ϕ_R is input to a first data converter 29, which may comprise the above first mentioned ROM together with a digital to analogue converter, and which provides an appropriate phase control voltage for application to electrode 14*b*. The phase data is also input to a second data converter 30, which may comprise the above-mentioned second ROM together with a digital to analogue converter, and which provides an appropriate amplitude correction voltage for application to electrodes 16 of coupler 4. The relative amplitudes P and Q are set by a Y-junction waveguide split at 5. The relative amplitude R is set by the optical coupler 4.

It is the post-detection filtering, the higher reference arm optical amplitude, and to a lesser extent the electronic correction of linearity and amplitude variations, that allows this device to work even though the output optical signal of the combined P and Q (6 and 7) arms is not purely single frequency. The resulting system will allow the transmission of very high frequency electrical signals with accurately controllable phase over optical links, signals of up to many giga hertz may be transmitted in this manner. This will allow the numerous advantages of optical fibres to be used rather than requiring bulky and expensive coaxial metal cables. The device may also be used to generate electrical signals of controllable phase which are 3, 5, 7 etc. times higher in frequency than the input electrical signal (f_m).

To summarise, the integrated optic channel waveguide device described above may be used for the generation and transmission of very high frequency electrical signals on an optical carrier. The phase of the detected electrical signal is imparted via an appropriate phase shift applied to the reference optical signal. The device employs only three optical

waveguide arms in contrast to the four arms of the previously produced device. Only sinusoidal modulation signals are used which allows high frequency of operation. Controlled phase output electrical signals may be obtained which are higher in frequency than the input electrical signal. High phase linearity and constant signal level are achieved by the use of a high level reference signal, post detection filtering, a controlled optical coupler and electronic input correction.

CLAIMS

1. An integrated optic arrangement including an integrated optic device and electrical drive means therefor, which device includes a substrate of electro-optically responsive material in which are defined an input optical waveguide, first second and third optical waveguide arms of substantially identical optical length, and an output optical waveguide, wherein the input optical waveguide is optically connected to each of the first second and third waveguide arms at their input ends, which first second and third waveguide arms converge at their output ends into the output waveguide, wherein a respective conductive electrode arrangement is disposed adjacent a portion of each waveguide arm whereby in use of the arrangement electrical fields for modifying the optical properties of the waveguide arm portions can be generated, and wherein the electrical drive means is such as to provide first and second sinusoidal electrical signals of frequency f_m for application to the electrode arrangements of the first and second waveguide arms, respectively, which first and second signals are substantially in quadrature, and such as to provide a d.c. electrical control signal for application to the electrode arrangement of the third waveguide arm, whereby in use of the arrangement electrical signals of frequency f_m, and odd multiples thereof, and of controllable phase are generated and transmitted on an optical carrier signal input to the device, the phase of the transmitted electrical signal being controlled by the d.c. control signal and thus the phase of the optical signal in the third waveguide arm portion.

2. An integrated optic arrangement as claimed in claim 1, including an optical detector having an electrical output, arranged to detect the output of the output waveguide and thus the transmitted electrical signal, and a filter for filtering the detector output around a frequency selected from the values f_m, and odd multiples thereof.

3. An integrated optic arrangement as claimed in claim 2, wherein in use thereof the peak amplitude of the optical signal in the third waveguide arm portion is larger than the peak amplitudes of the optical signals in the first and second waveguide arm portions whereby to improve the linearity between the phase of the optical signal in the third waveguide arm portion and the phase of the detector output signal.

4. An integrated optic arrangement as claimed in claim 3, including data converter means whereby an input digital signal indicating a desired value of the phase of the detector output is translated into a corrected value of the phase of the optical signal required in the third waveguide arm, and thus a corrected d.c. control signal, so that the desired value is exactly achieved.

5. An integrated optic arrangement as claimed in any one of the preceding claims, wherein the waveguides and waveguide arms are comprised by single mode waveguides.

6. An integrated optic arrangement as claimed in any one of the preceding claims, wherein another waveguide portion diverges to form the portions of the first and second waveguide arms, which other waveguide portion is optically connected to the input waveguide by means of an optical coupler.

7. An integrated optic arrangement as claimed in claim 6 as appendent to claim 2, wherein in use the amount of optical energy coupled into the other waveguide portion from the input waveguide may be adjusted by the application of an electric field across the coupler, and including further data converter means whereby the coupling of optical energy is adjusted such that the amplitude of the detector output of the desired frequency is substantially constant for all values of the phase of the optical signal in the third waveguide arm portion.

8. An integrated optic arrangement as claimed in any one of the preceding claims, wherein each electrode arrangement comprises two portions, which two electrode portions are arranged on the substrate surface on opposite sides of the waveguide, wherein one electrode portion is earthed and the respective electrical signal is applied to the other electrode portion.

9. An integrated optic arrangement as claimed in any one of the preceding claims, wherein the electrical signals applied to the electrode arrangements associated with the first and second waveguide arm portions include a d.c. bias.

10. An integrated optic arrangement substantially as herein described with reference to and as illustrated in Fig. 1 or Figs. 2 and 3 of the accompanying drawings.

11. An integrated optic frequency converter and phase shifter substantially as herein described with reference to and as illustrated in Figs. 2 and 3 of the accompanying drawings.

Printed in the United Kingdom for
Her Majesty's Stationery Office, Dd 8818935, 1985, 4235.
Published at The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.